Draft International Standard for Ground-based Automated Mobility: Loading and unloading at the curb and sidewalk

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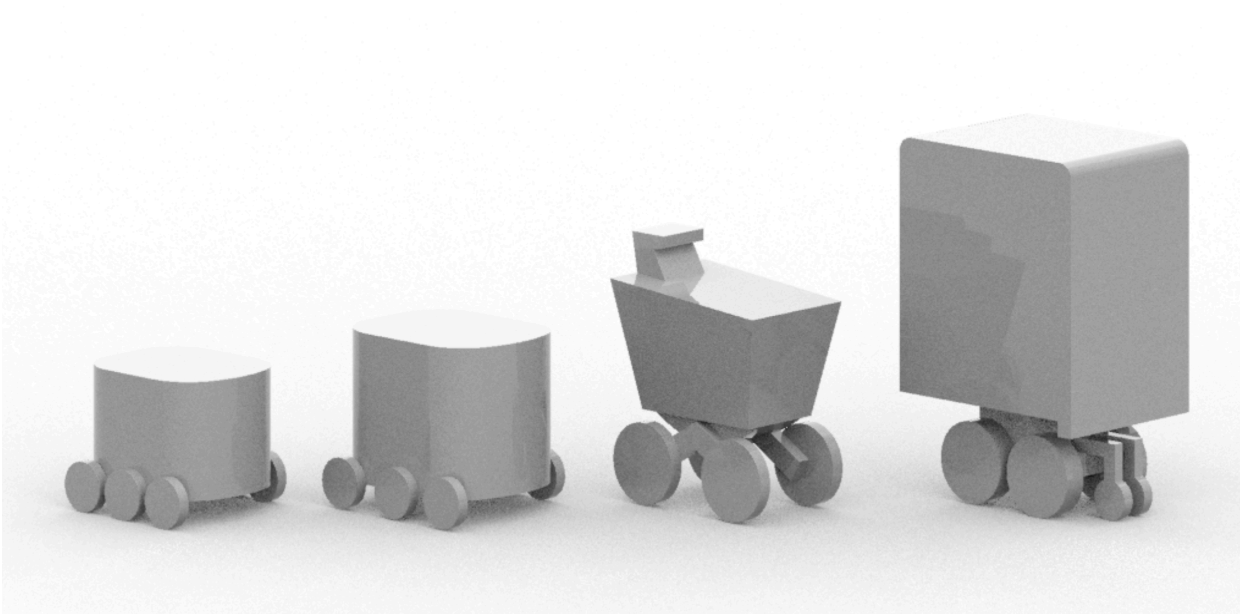
The arrival of automated vehicles at the urban curb and sidewalk (kerb and pavement) requires an overhaul of how we operate and monetize these spaces. This challenge requires increasing degrees of digitalization, new communication technologies for operation and coordination, and new collaborations between governing bodies and system providers.



A draft technical standard, ISO DTS 4448, is being prepared to define the operating data and procedures to guide ground-traffic control operations and inform relevant vehicle operators and system makers. This paper provides a preview of the intention, scope, and critical components of the draft standard.

Introduction

It is anticipated that in the very near future many urban and suburban jurisdictions will consider preparations for robotic cars, taxis and trucks and other forms of robotic vehicles for passengers and goods. At the same time and in the same places service robots may be deployed for maintenance activities such as snow removal, trash pickup, sweeping, or surveillance. The location for these vehicles and services will be in public spaces in towns and cities where curb and sidewalk space is already under increasing pressure for access by a growing variety of uses, innovations, devices, businesses, and services.

Over the past decade, digitalization of mobility and commerce has brought rapid growth in new forms of taxi-class operations loading and unloading passengers at city curbs as well as a dramatic rise in goods delivery from e-commerce systems. In some areas of larger cities this change has been rapid and has already reached unsustainable conditions. Some of these are being addressed on a local and urgent basis often without consideration of future change, growth, or innovation. In addition, the rise in active transportation has added cycling, scooter, and e-bike lanes at the curb in many cities, as well as scooter and bike storage on the sidewalk.

Since early 2020, the onset of the COVID-19 pandemic imposed yet more demands on these sidewalk and curb spaces, including social distancing, an uptick in micromobility, and in some cases increased demand for dining space. This tended to create wider sidewalk rights-of-way to accommodate the new demand. Additional width invites more variety and creates an even greater need for access management as social distancing continues, micromobility grows, walkability demand increases and the need for cleaning, maintenance, and snow removal for these expanded and complex places grows.

To this mix, we expect to add the delivery of passengers and goods using driverless vehicles that load and unload at the curb. As well, the last-mile delivery of goods via sidewalk delivery robots (SDRs), or personal delivery devices (PDDs) is contemplated. Indeed, prior to 2020, SDR systems were already operating including payment for service.

All of this implies further increases in traffic volumes at both the curb and on the sidewalk. The introduction of automated vehicles without human accompaniment will necessitate highly automated (digitalized) management. Taken together this will change the nature of the interactions among these vehicles and their control systems — with each other, with the curb, with payment systems, with active human mobility, and with our existing manual vehicles and devices.

The traffic and parking rules cities have relied on prior to 2020 represent governance that is already under stress, and their design and governance shortcomings have been made increasingly evident by the pandemic. Parking systems developed to date are insufficient to support the loading and unloading of the anticipated automatic vehicle systems without additional data and procedures to support *ground-traffic control systems*.

Cities will need new operating guidelines as curbs and sidewalks are joined by automated taxis and SDRs that arrive, stop, park, wait and load under sensor, effector, and software control. Unaccompanied by human passengers or attendants, these machines will need to be prioritized, scheduled, queued, bumped, and placed in holding patterns, and all without blocking crosswalks, bicycle lanes, micromobility users, no-stopping areas, or transit stops as are common taxi and goods-delivery infractions now. This must be done safely, mixed with human-operated vehicles, without inconveniencing active transportation users, pedestrian traffic, and with regard to human accessibility challenges.

Five intentions for standardizing curb and sidewalk automation

1. Safety and conflict-avoidance

As the number and variety of innovative mobility vehicles and devices, automated or non-automated enter into common use, the potential for spatial conflicts for vehicles arriving, stopping, parking, waiting, or loading and navigational conflicts when robots are passing, crossing, or overtaking can be expected to grow with the number and variety of such vehicles and devices. Spatial conflicts are already very common and cumbersome at many curbs and on many sidewalks. As increasing numbers of such vehicles and devices can be expected to operate without on-board human operators or even proximate human control, and potentially without the lane-markings that often guide on-street vehicles, machines that operate at curbs and on sidewalks, and sometimes both, must interact with each other and with human-operated vehicles and devices. This requires a set of agreed and tightly-communicated behaviours and guidelines for real-time resolution and those guidelines require terminology, procedures, communications, and systems.

2. Planning

Some projects to re-format and reorganize streets, curb or sidewalks will need to build and shape these spaces to be workable for vehicles and devices whose operating characteristics may be different, or differently constrained, than would be vehicles and devices under human operational control. Such planning activities need guidelines and those guidelines need common data and systems. They will also need more detailed metrics and design parameter descriptions as more such spaces are prepared for automation.

3. Commercial

Some curbs and sidewalks can be expected to be used more heavily by commercial vehicles (taxis, shuttles, trucks, sidewalk robots, etc.) each with various automated capabilities. These would be loading and unloading passengers and goods. The use of automated (driverless) machines for these activities, means forward-planning for logistics will be required. Such forward planning will need reservation systems updated in real-time. The design and execution of such reservation systems requires shared terminology, procedures, communications, and systems since we can expect multiple vehicle types, providers and operators.

4. Operations

The curb and sidewalk comprise the spatial context for people who reside or trade in the buildings at or near such curbs or sidewalks. People and goods who arrive or depart with the help of vehicles and devices, automated or not, or simply on foot, expect to be able to arrive and depart in a timely manner without finding a pathway or loading facility blocked and without unexpected long waits. These spaces need to be managed in a reasonably smooth and coordinated fashion. This requires shared communications and systems.

5. Legal, liability, and insurance

Any curb or sidewalk is a public space shared by many types of users including local residents, vendors, visitors, shoppers, whether able-bodied or not. Any conflict that causes bodily harm, financial loss, or other harm or perceived harm may be subject to legal or claim action. Hence a common understanding and description for these spaces and the expected machine behaviours in those spaces is necessary to assign or determine liability. This shared understanding and description requires common data, procedures and system definitions.

Standard components

This draft standard defines the data and communication systems needed to organize, expedite and safeguard the flow of automated vehicular ground traffic relative to the loading and unloading of goods and passengers, and the allocation and movement of service vehicles (garbage removal, sweeping, washing, snow removal, repair, food trucks, construction, etc.) in shared public spaces such as curbside, sidewalks, active mobility lanes, walkways and other pathway surfaces shared with pedestrians and other automated or non-automated vehicles.

Such systems are intended to enable carefully defined and growing areas (operational design domains) of cities to manage any number of vehicles and vehicle varieties operated by any number of operators (public, commercial, private) for these various activities.

The next sections look briefly at critical system components for managing public-system (urban) robotics. These roughly correspond to the current and planned parts of draft technical standard ISO 4448. Because this work will not be complete until circa 2024, this outline may differ from its final organization:

- Robotic road vehicles for passengers or goods
- Service robots for sidewalk and other public-space services
    - Guiding principles for operation of robots in public spaces
    - Guiding principles for governance of robots in public spaces
    - Similarities between sidewalk robots and human accessibility devices

    - Service robot access: surface conditions and path dimensions
    - Service robot access permissions
    - Service robot behavior
    - Service robot social communication
    - Integrating robotic curbside and sidewalk access
    - Robot cybersecurity
- Certification for use
    - Curbside and sidewalk certification for automation
    - Robot weather-worthiness

Robotic road vehicles for passengers or goods

Robotic ground transportation systems for passengers and/or goods comprise vehicles, load/unload places, schedules, prioritization algorithms, and management processes. An urban area that intends to permit or encourage the use of automated road vehicles, will experience a complex and growing number of these interacting and increasingly digitalized (fast, precise) components. A system to operate these will be analogous to an air-passenger system with numerous airplanes, flight operators, airports, and runways.

Current systems that match passengers to vehicles are plural, competitive, and disparate. Examples are taxi-dispatch and ride-matching services — each of which are sub-optimal, but workable. As well, a spatial conflict can be observed for goods movement systems matching shippers to couriers; it is commonplace to see two or more stepvans from competing express delivery operators standing in front of the same building each blocking a bicycle lane while delivering one or two packages. That is suboptimal from a traffic, environmental, and total cost perspective.

Systems that match robotic vehicles with load/unload spaces, such as in publicly shared parking areas at the curb, will require local or regional coordination, so must be collaborative. In other words, a single, effective management system is required to coordinate loading/unloading of all passenger and goods vehicles regardless of the number of taxi, shuttle or logistics providers operating within a bounded region.

To load/unload passengers at controlled locations requires procedures for vehicles or their operators to reserve, queue, and access spaces to load/unload at the curb or similar — i.e., mapped spots suitable to a passenger's start/end goals. The reason such a system needs to be singular within a given spatial domain is most public domains would admit multiple passenger and goods transport operators sharing a large number of loading/unloading places. This is analogous to a computer operating system managing an arbitrary number of programs and memory locations.

A system to manage loading/unloading of passengers is primarily concerned with trip terminus events and less with the routes between them although flow or congestion within those routes naturally affect the real-time management of terminating events. Uncertainty in trip times will cause re-scheduling, re-queueing, and complexities of storage for queues, such as "circling the block", double-parking, waiting areas (over-specification of parking areas), or queueing in-motion (a process of having vehicles alter their travel speed to time their arrival at a spot).

Flattening peak load/unload times would help this queueing process considerably and one way to do that is through the use of variable pricing of loading/unloading privileges. Since a load/unload management system will require computation, IoT devices, oversight, maintenance, and spatial infrastructure for the vehicles, it will need to be funded. The best way to match a transportation system's expense with its management is with variable use-pricing that is designed to flatten peaks.

Two critical elements related to both robotic passenger and goods mobility are safety and accessibility. Safety considers passengers, proximate pedestrians, as well as nearby vehicles and their passengers. Accessibility concerns are likewise three-fold — passengers, nearby pedestrians with accessibility challenges, and the accessibility considerations of proximate non-robotic vehicles.

This road-vehicle load/unload aspect of the standard needs a small set of data elements describing the location, dimensions, permissions, and availability of load/unload spaces and a matching set of data describing the vehicles requesting those spaces. In addition, a set of rules, procedures, and processes are needed to request, prioritize, match, enqueue, dequeue, and manage the inventory of load/unload spaces. Methods to price loading/unloading activities according to jurisdictional requirements can be added readily since these processes require real-time location, scheduling and monitoring.

Loading/unloading goods has all of the same ground-traffic control issues as does passenger loading and unloading in terms of requesting, prioritizing, matching, queuing, and inventory (space) management with some additional considerations in terms of size, noise, emissions, and hazardous materials.

While the standard is largely agnostic to whether a ground vehicle is carrying passengers or goods, it admits distinctions so as to permit a jurisdiction to control goods delivery schedules or locations differently from those of passenger systems. In this way, the standard can support separate loading areas for goods and passengers, dynamic loading areas that admit different vehicle purposes throughout the day, or even variable, on-demand mixing among modes without distinction in spatial allocation. This is done because it is not possible to predict the degree of segregation or mixing between passenger and goods systems into the future. Indeed, it is possible that passenger vehicles may also transport goods independently in the future either having the same vehicle perform different duties at different times (serial work assignment) or in the way that regional bus-passenger or air-passenger systems transport goods (parallel work assignment). Consider *Integrating robotic curbside and sidewalk access,* below.

Service robots for sidewalk and other public-space services

Robotic vehicles intended for services such as personal deliveries, snow removal, sweeping, surveillance, or other light duties on sidewalks, bike paths, road shoulders, or other urban pathways are a novel urban management problem.

Cities have managed the loading and unloading of road-vehicles on or at the curbside of roadways for centuries. Repurposing the current curb-management practices for automated road-vehicles is easy to contemplate, but most cities recognize that their ability in this has been sorely tested by high volumes of parked vehicles, upticks in e-commerce, active mobility modes, and now social distancing for the pandemic.

Considering these existing, unaddressed pressures, the management of even modest numbers of motorized, automated vehicles on urban walkways will be a daunting challenge. Worse, the current design and status of urban walkways is already challenging for many pedestrians.

At base, the fundamental logistics activities for automated vehicles at the curbside and on walkways is analogous: match and schedule vehicles to use identified spaces. At the curb, the spaces are loading or parking spots. On the sidewalk or pathway, the space is a block-face or a segment of pathway between two intersections or points.

But there are critical differences. At the curb, vehicles queue to become stationary in order to load/unload. For the pathway (sidewalk, crosswalk and bike lane) service robots queue to operate (move, navigate, work, and wait) in ways that are mixed with pedestrians of all abilities or active-mode users such as cyclists or scooterists. Pedestrians occupying this space walk pets, carry packages, push, drag or ride in wheeled devices, chairs, scooters or boards. They travel in small groups, meander slowly, stand in clusters such as at intersections or transit stops, and they window-shop, line-up, run, or weave from one side of the pedestrian clearway to the other. Such normal pedestrian behaviours are at risk of becoming less safe or more difficult due to the presence and movement of robots among these existing activities.

Depending on the prevailing view of the governance of public space (more below), such pedestrian behaviours may be protected or curtailed by the introduction of service robots. While the standard described here is agnostic to governance style or theory, it is designed to formalize communication and operation of any intended governance style.

The next three, paragraphs outline operational, governance and accessibility principles for sidewalk robots.

Guiding principles for operation of robots in public spaces

To guide the development of a formal standard for robot behaviour, a series of guiding principles are used:

1. Robots should grant **rights-of-way** to humans in close proximity, but rules of engagement may consider how to prevent a robot from being immobilized for an extended period in crowded circumstances. There may be explicit exceptions in the case of service

robots as actors in emergency (police, fire, ambulance) contexts.

2. Robots must be deployed to respect the cultural and contextual inter-pedestrian distances normally observed when walking or standing in a public place, known as **shy distance**. This may be extended to **social distance** in the event that robots are identified as a disease vector.

3. Robots must **not harm or alarm** humans or animals on the sidewalk.

4. Robots must be **apparent** (visible and/or audible) to all humans on the sidewalk (flags, lights, sounds). This is not only to accommodate people who may have visual or auditory challenges but to avoid mishaps with distracted pedestrians. This is related to not harming or alarming humans.

5. Robots must **signal** their presence, priority, and certain properties to other machines. This enables rights-of-way decisions and can help differentiate autonomous mobility devices from human operated devices, humans, and non-mobility entities.

6. Robots must not diminish the **privacy** of humans or businesses using or residing near sidewalks. This implies constraints on the recording and retention of data.

7. Robots must not diminish the **security** of humans, businesses or other machines on the sidewalks. This is also in regard to the security of humans residing and trading near such sidewalks. This includes both physical and cybersecurity.

8. Robot infrastructure must be **non-intrusive**. Robots may be guided by localized infrastructure, high-resolution mapping, and other data or technologies, but any additional infrastructure cannot negatively affect (make more cluttered, riskier, more confusing, or less accessible) the use of this shared space by humans.

9. Robot **occupancy** within a defined area must be controllable to prevent unacceptable congestion in public areas and on walkways.

10. Robot **waiting and stand-aside** behaviours must not create obstacles for pedestrians. This impacts how robots may position themselves when pedestrians pass, wait at intersections, or travel at the edge of a walkway.

Guiding principles for governance of robots in public spaces

In her 2020 paper, “Robots, Regulation, and the Changing Nature of Public Space,” Kristen Thomasen outlines three views of public space that might guide a regulator of sidewalk robots: Communal Public Square, Regulated and Orderly Public Square, or State-Owned Property. Depending on how these views influence relevant regulations, robots would be governed locally in more or less restricted ways.

An international standard must necessarily be agnostic to such legal theory. The primary goal of standardization is its role in equipment, system, operation, and process design and certification. However, since the machines, systems and processes being standardized operate in public spaces, in large numbers, for many purposes, and among many pedestrians, the deployment of a standard must necessarily impact, and be impacted by, governance.

Hence, it is critical to ensure necessary and sufficient operating data and procedures so that the respective socio-legal preferences can be supported in any country, state, or city by way of constructions that allow legislators to adapt the standard to their governance needs and be able to communicate relevant rules to makers, operators of automated devices, and their users (carriers and shippers). Correspondingly, makers and operators of robots can anticipate and comply with the resulting rules.

In the simplest view of safe personal space for pedestrians, a clear space in the direction of travel must be open in order for a robot to proceed. The proximate, realtime issue comes down to whether the size and comfort of that clear space is such that pedestrians are not made worse off in terms of access, safety, convenience, or peaceful enjoyment of that public space.

Rules that have robots yield right of way and respect shy distance imply an optimal, clear space in this immediate realtime sense, but such rules do not prevent robots from entering a dynamic space that could, after a short time, develop into a circumstance that inconveniences or delays pedestrians or adds to pedestrian congestion potentially made worse as a consequence of the presence of the robot(s).

Robot navigational rules that operate by opportunistically moving into clear spaces as they open up (greedy algorithms) are essentially how humans navigate on busy sidewalks and cars operate in traffic. If such was the only local decision approach employed by a robot, then as these robots become more capable, nimbler, and more numerous, human pedestrians, especially those who are older or less nimble, would become increasingly disadvantaged as robots are enabled to dart opportunistically wherever possible. Average human skill as a pedestrian is unlikely to improve, but over the next decade robot skill will improve dramatically. In unregulated, congested circumstances, this could become deleterious to human rights-of-way.

Several instances of current U.S. state legislation that have been enacted since 2017 indicate that robots (called personal delivery devices in these documents) must always give way to pedestrians. This behavioral constraint is necessary but insufficient in the case of the use of greedy spatial algorithms.

For this reason, the standard provides data and procedures to control the ingress of robots to a block-face or pathway segment so that their occupancy (count) at any one time can be limited. This reduces, but does not eliminate, the effect of greedy spatial algorithms.

Related to this, it is possible for a robot that must always give way to pedestrians and to maintain a shy distance to find itself trapped for unexpected or unintended periods of time especially in congested foot traffic ("robot trap" problem). Naturally, operators of such robots would like to avoid such circumstances, but it may not be possible to do so on every occasion. This is another reason to consider occupancy counts at block-faces according to sidewalk configurations and times of day so as to minimize the likelihood of such events, and minimize extraction time when one occurs.

As robots become smarter, we can imagine that they might acquire, through machine learning, more foresight to further reduce the probability of being trapped among pedestrians or other robots. In the meantime, the standard provides a way to minimize the likelihood of this outcome and provides a level of governance that acknowledges local contexts so that occupancy limits may act locally or dynamically.

Similarities between sidewalk robots and human accessibility devices

There are a number of useful comparisons between wheeled sidewalk robots and pedestrian accessibility devices such as wheelchairs or assistive scooters.

As a vehicle, the wheeled (non-ambulatory) sidewalk robot has some characteristics similar to a wheelchair, it can easily travel faster or slower than the average human (walking) pedestrian, it confronts issues of traversing uneven, damaged, steep, sloped, or potholed pavement or ramps (curb cuts). It cannot "step aside" as an ambulatory, abled pedestrian normally can, and it cannot streamline its width by turning sideways while walking as an abled pedestrian can. Basically, the wheeled sidewalk robot exhibits many of the rigid physical and motion constraints and properties of a pedestrian wheelchair. Depending on wheel diameter, number of wheels and their suspension system, a robot may have somewhat different constraints compared to a wheelchair.

As a machine, the sidewalk service robot might be relegated fewer social rights or diminished rights-of-way compared to a pedestrian. Conversely, as a working machine it may be an actor in an entitled social role, i.e., it may be performing a service critical to someone with special social rights. Perhaps some specially-marked robots might inherit those rights in the way that a registered service dog inherits certain social rights-of-way from the human it is helping. A sidewalk robot may be unable to cross certain path elements that an able-bodied pedestrian can readily traverse, it may be subject to vandalism or mischief in ways that are different or more frequent than those confronting a wheelchair user, or it might have a very much lower height profile compared to a wheelchair user, making it less apparent to pedestrians who are a short distance away, unless specially equipped in some way (flag, lights, sound, or beacon).

As an automated machine, the sidewalk robot would have no onboard or proximate human to provide or receive social signals. It may be programmed to send and receive social or directional signals and to exhibit more patience than does the average human. As a semi-automated machine, it might be teleoperated, but the ability of a teleoperator to engage in social signaling would likely be limited. An example of this might be a teleoperated micro-mobility device such as a self-standing e-scooter being guided back to a docking station. The eventual introduction of ambulatory SDRs will add still other considerations, relieving some constraints and adding others.

These three comparisons suggest that a standard for sidewalk robots should consider alignment with existing accessibility standards relative to wheelchair use. Such goal-congruent alignment provides opportunities to address sidewalk design and configuration to intentionally benefit accessibility goals while standardizing robot access and flow.

Service robot access: surface conditions and path dimensions

A ground-based robot is designed to effectively and safely operate with respect to a given set of surface conditions. Because a standard for service robots cannot anticipate all possible robot designs in terms of weight, wheel diameter, or other physical properties related to roadworthiness, the standard defines a way describe the surface properties of a pathway such that a logistics operator can make a decision — likely automated — regarding the relative roadworthiness of a vehicle to travel on a particular surface.

There are many aspects to surface condition and path dimensions that make up a particular set of conditions. These may be built, transient, temporary, or environmental, such as pavement width, garbage bins, construction, or ice, respectively. The standard specifies metrics such as roughness, firmness, stability, friction, and several other elements related to surface attributes. It also specifies metrics such as path width, height, and gradient which taken together with several others form the basis of a navigability or accessibility calculation to be used for real-time logistics decisions. A separate part of the standard, below, addresses climate and weather features.

Many of these metrics and their defaults have been gleaned from accessibility manuals related to wheelchair use. Drafted this way, biases for robots that are similar in size, weight, and wheel-type to commonly specified wheelchairs. This implies that any infrastructure preparation for automated vehicles on pedestrian pathways could easily benefit accessibility users at the same time. It is currently the case that very many sidewalks in our cities do not fully comply with the accessibility guidelines of their respective jurisdictions.

Nonetheless, the sidewalk robot standard sets the information needed to perform a standardized accessibility calculation for machines with specific attributes known to their operator. It is the governing jurisdiction that sets and certifies pedestrian zones for accessibility by either humans or machines. The point of using the same metrics and parameters is to ensure that a designer of a shared pedestrian-robot space can be enabled *by default* to address human accessibility certification at the same time.

Service robot access permissions

Access permissions differ from access conditions. In the case of access conditions, above, a jurisdiction is declaring information about the pathway. In the case of access permissions, the jurisdiction is demanding information about (promised behaviour from) the machine.

A governing jurisdiction may constrain access by restriction (e.g., weight, width, height, length, noise, emissions and schedule), and by requirement (e.g., lights, sounds, flags, and registration display).

It is the 3-way match among what a pathway offers, what a robot declares, and what a logistics operator requests (such as schedule and then-current robot counts) that enables the assignment between the robot and its route along a number of specific, mapped surfaces such as sidewalks, lanes, shoulders, or crosswalks associated with blockfaces or other pathways.

Access permissions are affected by the purpose of the service robot. The route plan and permissions for a small SDR would be very different from the route permissions of a robot snowplow. For this reason, the V2X system managing information about conditions, dimensions, and permissions will require real-time monitoring. Today these robots are either pilots or controlled by a dedicated operator within a constrained operating domain, and monitoring of route conditions is done by humans generally through onboard cameras.

When we reach a plurality of fleets, operators, and service purposes, consistent human teleoperation will become unworkable except for emergency oversight and resolution. Fully digitalized coordination from ground control systems using IoT networks and real-time scheduling systems will be required.

Service robot behaviour

Once a robot's route is determined and granted, the device is expected to behave in particular ways. This will mostly be mediated by software within the machine as governed by local settings and limits. These behaviours include speed, travel side, travel direction, shy distance, schedule, and several aspects regarding waiting, rights-of-way, and clustering. These behaviours comprise what are essentially "rules of the road" for service robots in public, shared places/spaces. In this regard, the standard would inform many of the elements of a jurisdiction's "sidewalk traffic act".

Importantly, there would be a need for local and variable changes to settings and limits — perhaps delivery speed or street-sweeper access changes by time of day or current block-face traffic. These changes need to be reliably communicated to the machines in near real-time and to be effective must be ensured or enforced.

Service robot social communication

One of the special aspects under development for the standard are uniform movement indicators and social communications. Because pedestrian traffic can be more chaotic than motor vehicles in traffic lanes, robots will need a bounded, but precise vocabulary of lights and sounds.

Simple examples would be to signal a turn, or to grant a right-of-way. Other examples include signals for apology, request, gratitude, and alarm to act as a machine replacement for the glances, gestures, vocalizations, and body language that pedestrians use now. These are being designed for the safety of both pedestrians and the robots, and to increase the social acceptability of these robots.

Robots need to signal their intentions and moods in language- and culture-independent ways. Such signals will be matched pairs (lights and sounds) so as to be understood by pedestrians with auditory or visual challenges.

Integrating robotic curbside and sidewalk access

One of the projected use-cases for robotic goods-delivery is a larger delivery van stopping at the curb or other location proximate to several deliveries, and releasing one or more pedestrian-scaled robots to complete deliveries on sidewalks or walkways.

To make this work, a degree of coordination is needed between the load/unload reservation for the delivery van and the reservation (permission) needed for the sidewalk robot(s) to travel on the intended walkway(s). This is provided in the standard.

Such an operational real-time coordination between curb and sidewalk is new and will be a mapping and data challenge for those larger cities for whom these domains are currently handled by separate departments.

Robot cybersecurity

The standard provides requirements and guidelines for secure application services data interfaces between vehicles and infrastructure. These are based on existing credentialing standards in ISO 21177 and ISO 5616.

Certification for use

Curbside and sidewalk certification for automation

A critical aspect of preparing for automated vehicles at the curb or on walkways is to determine the readiness of a specific subset of curbs, sidewalks and crosswalks. This question can be asked in two ways: "Can a jurisdiction safely provide permission to deploy a described type of automated taxi or sidewalk robot at a particular curb or sidewalk?" or "What preparations must be made in order to safely attract deployment of a certain type of automated vehicle or sidewalk robot at this particular curb or sidewalk?"

Whether a jurisdiction is asked to permit these vehicles and devices or whether it, or a community association, seeks to attract them, a *gap analysis* is required based on a standardized readiness model. This involves considering multiple system and governance attributes for several classes of vehicle capabilities. Here are a few examples from a much longer list:

1. What must be done to ensure robotaxis are not loading or unloading in traffic or on bicycle lanes?

2. For a given level of automation to be permitted (or encouraged), what human-readable signage is appropriate?

3. What regulations should be in place for teleoperated robots? For fully autonomous devices?

4. What sounds, lights, signals, or markings should be regulated for these vehicles or devices to ensure compliance with accessibility guidelines?

5. When and how can city enforcement personnel (police) stop, examine, rescue, or seize a robotic machine?

Answers to such questions are dependent on the automation and IoT capabilities under consideration. Hence, the standard details multiple readiness attributes for each of several "maturity" classes of curbside and sidewalk operating domains. These attributes and maturity classes define a readiness matrix to be used to gauge the automation readiness of a curbside, block-face, pathway, or a larger, contiguous area of curbs and walkways.

The sidewalk and curb are independent of each other, so that a curbside and its adjacent sidewalk may be categorized at different maturity levels. This has implications for automated logistics that may require integration between road vehicles and sidewalk vehicles such as SDRs.

Robot weather worthiness

Robots, especially smaller human-scale machines that might be designed for walkway use at pedestrian speeds and weigh under 50 kilograms, may be less capable in extreme weather or climate conditions than would be the cars or trucks we use today. Some of these conditions might disable such robots leaving them as walkway hazards. Severe weather conditions such as extreme winds might blow a robot into road traffic, or cause a robot to become airborne and slam into a pedestrian, a shop window, or a car.

The standard identifies a body of weather-worthy and road-worthy criteria for matters of temperature, wind, rain, snow, ice, and sand. The standard describes criteria for certification of machines and conditions such that a jurisdiction can determine when various devices must suspend operations and return to a protected storage area.

Parameters

Each of the data elements described above needs to be parameterized by a governing jurisdiction. Updates to these parameters are sometimes required in near real-time (surface friction). Others require notice to allow logisticians to plan (maximum weight). Most, but not all have tolerances (max height, ± 20mm). All have update rules.

Procedures

When a ground control system is operating, there are procedures for activities such as Reserve, Queue, Relinquish, Reschedule, etc. Many of these activities are precisely standardized. Other activities such as impounding a robot are only suggested, and its specifics are not standardized.

Schedule

As of this writing, the standard is currently slated to have 11 parts, three of which are in the working draft stage and the remainder are outlined. This work started in April 2020. It is expected to be published in stages and to be completed by 2024. ■■■

